Piloerection is not a reliable physiological correlate of awe.

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Abstract

In scientific and popular literature, piloerection (e.g. goosebumps) is often claimed to accompany the experience of awe, though this correlation has not been tested empirically. Using two pre-registered and independently collected samples (N = 210), we examined the objective physiological occurrence of piloerection in response to awe-inducing stimuli. Stimuli were selected to satisfy three descriptors of awe, including perceptual vastness, virtual reality, and expectancy-violating events. The stimuli reliably elicited self-reported awe to a great extent, in line with previous research. However, awe-inducing stimuli were not associated with the objective occurrence of piloerection. While participants self-reported high levels of goosebumps and "the chills," there was no physical evidence of this response. These results suggest that piloerection is not reliably connected to the experience of awe—at least using stimuli known to elicit awe in an experimental setting.

Keywords: *Awe, piloerection, goosebumps, emotion, physiology*

1. Introduction

The occurrence of goosebumps is often claimed to accompany the emotional experience of awe, both in the scientific literature (Maruskin et al., 2012; Quesnel and Riecke, 2018; Schurtz et al., 2012; Stellar et al., 2017; Stepanova and Hennessy, 2018) and in popular press (e.g., Chibber, 2015; Keltner, 2016; Piff & Keltner, 2015; Stone, 2017). Consider for example the following quotes:

> "In humans, piloerection shifted in its use, coming to occur regularly when we ourselves feel expanded beyond the boundaries of our skin…" *Keltner, 2009, pages 446-447*
>
> "When you gaze up at these trees, with their peeling bark and surrounding nimbus of grayish green light, goosebumps may ripple down your neck, a sure sign of awe." *Keltner, 2016*

After reading such quotes from scientists in the media, you may feel confident that science has shown awe to cause goosebumps. Surprisingly, this relation has not been tested empirically. However, many studies do claim to have tested this relation or cite articles claiming to have tested it:

> "Relative to the shivers, goosetingles involved greater awe…" *Maruskin, Thrash, & Elliot, 2012, abstract*
>
> "Goose bumps resulting from the emotion of awe were the second most frequently occurring type after reactions to cold" *Schurtz et al., 2012, abstract*
>
> "In addition, awe is associated with biological changes in the form of piloerection (goose bumps), a specific response of the sympathetic autonomic nervous system (Maruskin, Thrash, & Ellliot, 2012)." *Stellar et al., 2017, page 203*
>
> "However, the body gives some clues as to when awe might occur. Among these clues is the sensation of the "chills"… and often their occurrence with visual piloerection, commonly known as goosebumps (Benedek and Kaernbach, 2011; Grewe et al., 2009a; Keltner and Haidt, 2003; Nusbaum and Silvia, 2011; Stellar et al., 2017)." *Stepanova & Hennesey, 2018, page 29*

However, further inspection will reveal that these studies only used retrospective self-reports or, in some cases, didn't actually measure awe at all. Further complicating things is that there is little correspondence between self-reported and objective occurrences of piloerection (Benedek and Kaernbach, 2011). Thus, the popular belief that awe causes goosebumps lacks empirical support and research is needed to examine whether awe is indeed associated with the objective occurrence of piloerection.

Researchers have speculated as to why awe and piloerection may be related, though these reasons are not always consistent. For example, researchers describe awe as an “epistemic emotion” that is related to facing and understanding the vastness of the world (Keltner and Haidt, 2003; Michelle N. Shiota et al., 2007). Because the experience of awe is expected to “mobilise” one to learn more about the world (Shiota et al., 2011), researchers have expected awe to be distinguishable from other emotions in terms of autonomic activity (Oveis et al., 2009; Michelle N. Shiota et al., 2007). Because awe is associated with amazement and wonder, one could imagine that this might reflect a parasympathetic state. On the other hand, awe has also been associated with negative experiences, such as threat and fear (Gordon et al., 2017) which is often associated with sympathetic arousal.

Indeed, piloerection is an autonomic response; however, the arrector pili muscles are innervated mainly by the sympathetic nervous system (Donadio et al., 2019). Thus, one should expect piloerection to be accompanied by markers of sympathetic activity. In contrast, research has found that awe is associated with both sympathetic withdrawal and parasympathetic activation (Chirico et al., 2017; Shiota et al., 2011). Thus, awe (a parasympathetic response) should not necessarily co-occur with piloerection (a sympathetic response) despite broad conceptualisations of awe as an indicator of autonomic activity (Stellar et al., 2017).

There is one article that claims to provide evidence that the experience of awe correlates with the objective occurrence of goosebumps (Quesnel and Riecke, 2018), but that study included only 16 participants and used only virtual reality stimuli. By contrast, there is a very large literature on awe and many studies claim to have induced it experimentally.

In the present studies, we test the hypothesis that awe causes piloerection by using stimuli known to elicit the emotional experience of awe and examining whether they reliably elicit piloerection. Awe has been elicited by stimuli with several characteristics. First, “perceptually vast” stimuli is said to be associated with the experience of awe (Keltner & Haidt, 2003). For example, videos of space and nature reliably elicit awe

(McPhetres, 2019; Valdesolo and Graham, 2014; Van Elk et al., 2016). Second, virtual reality technology has been noted to be a strong inducer of awe (Chirico et al., 2017; Gallagher et al., 2014) perhaps because it presents the same perceptually vast stimuli via an immersive medium. Third, awe is discussed as resulting from a "violation of expectations" (Paulson et al., 2020; Michelle N Shiota et al., 2007; Silvia, 2010; Taylor and Uchida, 2019; Valdesolo, 2016). That is, when we encounter an experience contrary to what we expect or understand about the world, such as sudden changes in music or violations of the laws of physics.

In this study, we selected stimuli to induce awe according to each of the above criteria. We observed the objective experience of piloerection in response to each set of stimuli. We hypothesized that awe would correlate with self-reported goosebumps and chills and with objective piloerection, and that stimuli eliciting greater awe would result in stronger awe-piloerection correlations. The study was pre-registered prior to data collection: https://osf.io/evtbj. Data and materials are available online: https://osf.io/5q96f.

2. Method

2.1 Participants. The two samples were collected concurrently. Sample size was determined by the available participant pool with the goal of recruiting 100 subjects or stopping at the end of the semester, allowing for the detection of effect sizes larger than d = .25 80% of the time in a one-tailed, within-subjects design with alpha = .05.

Sample 1 was collected from undergraduate students at the University of Rochester (New York, USA). There were originally 156 students (M_{age} = 20.39, SD_{age} = 1.23), including 43 males and 112 females (1 did not complete demographics). Twenty-three subjects experienced problems or issues with either the audio or video (e.g. buffering, accidentally exiting the video, trouble focusing the VR headset) and were excluded from all analyses according to our preregistered plans. This results in a final sample of N = 133.

Sample 2 was 77 undergraduate students (58 females and 16 males) at Occidental College (California, USA); 9 are missing piloerection data due to collection issues or stopping early and are excluded from relevant analyses. Participants ranged in age from 18 to 23 (M_{age} = 19.57, SD_{age} = 1.27). Though we pre-registered three samples, data for the third sample was unfortunately not collected due to miscommunication. Thus, we elected to cease the study after two of the samples were collected at the end of one semester in line with pre-registered plans.

3. Method

3. 1. Sample 1. For sample 1, subjects arrived at a laboratory session and were seated at a desktop computer in a private room. The purpose of the experiment and the procedures were described to participants and informed consent was obtained. The study was described as an effort to understand emotions and physiological reactions. A camera was attached to the non-dominant forearm (Benedek et al., 2010) and recorded approximately 1 square inch while the subject watched three videos. As the research assistant connected the camera, they explained that it would record their skin so that we could determine if they experienced goosebumps during the videos. We chose to explain it in this manner so as to hopefully increase awareness of goosebumps (and thereby accuracy of self-reports). Participant visibility of their own forearms was not obstructed. However, we did not explicitly instruct participants to pay attention to whether they experienced goosebumps because we did not want to distract from their attention to the videos. After the experiment was set up, participants were left alone so as to increase immersion in the videos.

Subjects viewed three videos; completion time was about 20 minutes. The first video was a control video intended to induce humour and amusement (BBC's *Walk on the Wild Side*). The second two videos were presented in randomized order. One was an emotional video with a surprise ending (Johnny Walker's *Dear Brother*) intended to induce surprise and unexpectedness (eg. a violation of expectations). The other was a 3D, 360-degree virtual reality video of the aurora borealis which has been demonstrated to elicit awe in previous research (McPhetres, 2019). Materials are available on the OSF page. After each video, subjects removed the camera and then completed a survey.

3.1.1. ***Open-ended emotion descriptors.*** The survey first asked subjects to write down two words describing the emotions they experienced during the video. These words were analysed for frequency.

3.1.2. ***Emotion adjectives.*** Subjects rated 8 emotion adjectives (including a single item for "awe") on scales from 1 (not at all) to 7 (very much). Items were selected to distinguish between each video: humour and joy for the control video, sadness and love for the emotional video, and calmness and awe for the VR video. Uncertainty, anxiety and anger were additional emotions not expected to be elicited. Because reliabilities were not consistently above .80, items were analysed individually as per our preregistration.

3.1.3. ***Awe.*** Awe was measured two ways to capture possible variation. First, awe was included as an emotion adjective. Second, a three-item scale (adapted from van Elk et al., 2016; αs = .66, .78, .83), was used to capture additional experiences of awe.

3.1.4. ***Surprise and unexpectedness.*** Subjects answered three questions about the unexpectedness of the ending and surprising nature of the video (αs = .85, .86, .86) on scales from 1 (not at all) to 7 (very much).

3.1.5. ***Self-reported goosebumps.*** Subjects were also given a description of goosebumps and the chills:

> Often when people feel emotionally moved, they may experience the sensation of chills down the spine, the shivers, or goosebumps/goose pimples. These may seem similar but there is an important difference:
>
> - goosebumps/goose pimples are visible by looking at the raised hair on some part of your body (arm, neck)
> - "the chills" does not need to be accompanied by this

After reading this description, they were asked to self-report the extent to which they experienced goosebumps and the chills on scales from 1 (not at all) to 7 (extremely).

3.2. Sample 2. For Sample 2, subjects were seated at a laboratory computer where they were connected to a camera and watched three videos. Subjects were told that the camera was recording their skin for evidence of goosebumps, and the skin of their forearm was left visible, similar to Sample 1. Subjects were randomly assigned two conditions where they watched a video that violated expectations and one that was expectation-consistent. The expectation-violating video was either about gravity or buoyancy; the expectation-consistent was then the other option. The order of the expectation-violating and expectation-consistent videos was also randomized. The third video was always a montage of BBC's Planet Earth which has been shown to induce awe in past research (McPhetres, 2019; Valdesolo, 2016; Valdesolo and Graham, 2014).

After each video, subjects responded to self-report questions about awe and surprise rated on scales ranging from 1 (not at all) to 100 (extremely). However, because data for this sample was being collected for other purposes, the format of the survey was different and included several other questions that are not relevant to the present investigation and are not analysed or reported here. The full set of questions asked for Sample 2 is available on the OSF page. Finally, subjects completed demographics.

3.3. Piloerection. Our preregistration outlined the use of the gooselab software to analyse videos (Benedek et al., 2010). However, the non-operation of the batch analysis function, severe movement artefacts, and several blurry videos in Sample 1 precluded consistent use of the software. The cameras were effective at detecting piloerection, which was very obvious when it did occur. Thus, we simply coded the videos for both samples manually.

Rather than using a subjective coding approach and correcting for coder disagreement, we took the perspective that piloerection should be objectively observable in the videos when it did occur. Thus, we took an iterative approach to coding. First, two research assistants (blind to condition, hypotheses, and sample) coded videos from one sample each. Then, the first author reviewed the videos and the ratings; at this point the videos were only named with an id code, so the first author was also blind to the video condition. Through discussion, the two coders then resolved disagreements. This achieved 100% agreement on ratings and maximised accuracy while minimising additional data and noise (e.g. from correcting for subjective ratings). A three-point rating system was used: -1 (no piloerection), 0 (slight piloerection or hair erection without visible muscle contraction), 1 (clearly visible piloerection with visible muscle contraction).

4. Results

For all of the analyses reported below, we took a two-stage approach. First, we follow our preregistered plans and conduct frequentist tests for our main hypotheses: alpha level was set at .05 and, where applicable, we use no *p*-value correction. Second, we perform Bayesian tests for each test to quantify evidence in favour of the null to further explore the small and nonsignificant effects reported herein.

4.1. Sample 1

4.1.1. ***Did the videos elicit the expected self-reported emotions?*** The videos appear to have elicited the expected self-reported emotions; inferential statistics are presented in Table 1, below. Further, as can be seen in Table S1, the control video was associated with increased humour and joy, the emotional video with increased sadness and love, and the VR video with increased awe and calmness. Further, the word-clouds for each condition suggest that participants spontaneously described the expected emotions. Experiences during the control video were described as happy and amused, the emotional video was described as sad, confused, calm and moved, and the VR video was described as awe, amazed, and relaxed (see Figure 1).

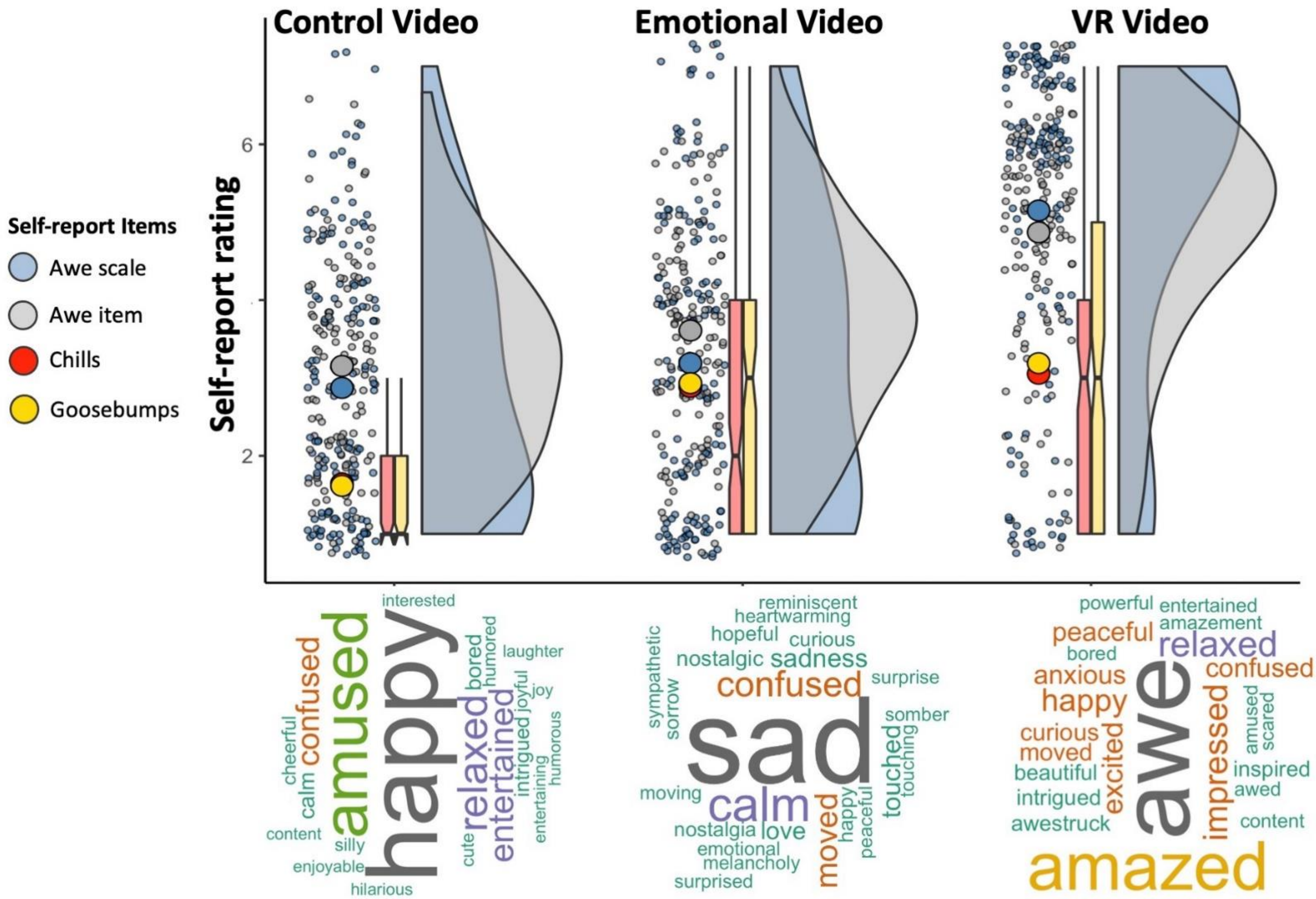
4.1.2. ***Does piloerection correlate with self-report measures?*** For the control video, piloerection did not correlate strongly with any other measure. For the emotional video, however, piloerection correlated positively, but only weakly, with self-reported chills and goosebumps but negatively with the single awe item; it was not correlated with the awe scale. For the VR video, piloerection correlated positively with the awe scale, the single awe item, and with self-reported goosebumps and somewhat weaker with chills. Across the three videos, only one correlation was associated with a p-value of less than the conventional .05 level (see Figure 1): piloerection with self-reported chills for the emotional video. Though several other correlations were close to the same magnitude, these correlations may be driven by the few instances of piloerection rather than by a consistent relation between the measures. However, a Fisher's r-to-z comparison suggests that these correlations do differ strongly from each other. For example, the largest correlation difference—between the awe scale and piloerection for the VR video ($r = .14$) compared to that for the control video ($r = -.08$)—yields $z = 1.65$, $p = .098$, suggesting that this difference is small given the sample size.

4.1.3. ***Frequency of piloerection.*** Overall, the categorical objective occurrence of piloerection was quite low: $n = 1$ for the control video, $n = 6$ for the emotional video, and $n = 5$ for the VR video (3% in total across three videos; see S2 Table for complete counts). This is lower than recent reports which have shown piloerection to be more strongly associated with other emotional states, such as kama muta (Zickfeld et al., 2020). Surprisingly, 59% (across all three videos) self-reported experiencing goosebumps and 61% self-reported experiencing chills (counting those who answered above the lowest point on the scale).

4.1.4. Quantifying evidence for a null effect. Because we report null effects of condition on the occurrence of piloerection, we calculated JZS Bayes factors in favour of the alternative and null hypotheses. This analysis was not preregistered. A repeated measures ANOVA comparing levels of piloerection across each of the three videos yields a $BF_{10} = .093$; this converts into a $BF_{01} = 10.75$ in favour of the null hypothesis. Thus, our data is over 10 times more likely under the null model than under the model in which the awe-eliciting videos cause goosebumps.

The frequentist correlation analyses also indicated near-zero relations between piloerection and awe for each of the videos. Here, we quantify that evidence using Bayesian analysis. For the control videos, evidence in favour of the null was greater than for a correlation between piloerection and the single awe item ($BF_{01} = 4.81$) and between piloerection and the awe scale ($BF_{01} = 3.31$). The same was true for the emotional video ($BF_{01} = 1.86$, and $BF_{01} = 5.00$) and the VR video ($BF_{01} = 1.16$, and $BF_{01} = 1.51$), respectively.

Fig. 1. Distributions of self-report items, qualitative emotion descriptors, and zero-order correlations for each video in Sample 1. Large coloured dots indicate mean values; boxplots indicate median and quartiles of self-reported chills and self-reported goosebumps, with notches indicating 95% confidence intervals around the median; S.R. = self-reported; *p < .05, **p < .01.



Variable	Control Video 1	2	3	4	5	Emotional Video 1	2	3	4	5	VR Video 1	2	3	4	5
1. Awe scale															
2. Awe item	.40**					.41**					.31**				
3. Unexpected	.30**	0.05				.19*	.32**				.18*	-0.13			
4. S.R. Chills	.19*	-0.06	0.15			.50**	.43**	.31**			.47**	0.06	0.09		
5. S.R. Goosebumps	.28**	0.03	0.14	.73**		.44**	.38**	.27**	.75**		.47**	-0.01	0.15	.75**	
6. Piloerection	-0.08	0.01	-0.11	-0.05	-0.05	0.01	-0.13	-0.03	.19*	0.15	0.14	0.16	0.05	0.1	0.11

Table 1. Inferential statistics, means, and effect sizes for omnibus repeated measures analyses on each dependent variable in Sample 1. All analyses here include $N = 115$ due to listwise deletion; means sharing asterisks across columns are not statistically different; bolded items are consistent with expected mean patterns.

				Control video	**Emotional Video**	**VR video**
Variable	F	*p*	η^2	Mean (SD)	Mean (SD)	Mean (SD)
Humour	8.12	< .001	0.88	**5.54 (1.24)**	1.3* (.68)	1.43* (.87)
Joy	133.43	< .001	0.54	**5.37 (1.40)**	2.56 (1.57)	4.77 (1.67)
Sadness	421.56	< .001	0.78	1.21 (.63)	**5.14 (1.20)**	1.91 (1.21)
Love	77.29	< .001	0.4	2.79 (1.68)	**4.81 (1.66)**	3.08 (1.73)
Calmness	22.92	< .001	0.17	4.44* (1.63)	4.24* (1.52)	**5.39 (1.58)**
Awe (scale)	98.66	< .001	0.46	3.12 (1.27)	3.65 (1.31)	**4.89 (1.45)**
Awe (item)	68.35	< .001	0.38	2.9 (1.71)	3.3 (1.92)	**5.24 (2.05)**
Uncertainty	21.24	< .001	0.16	2.2 (1.63)	3.52 (1.91)	2.55 (1.99)
Anger	.682	0.506	0.01	**1.16* (.62)**	**1.21* (.59)**	**1.14* (.50)**
Anxiety	6.24	0.002	0.05	**1.41 (.92)**	**1.89* (1.30)**	**1.76* (1.41)**
Unexpectedness	113.98	< .001	0.5	2.7 (1.43)	**4.49 (1.59)**	2.05 (1.19)
Chills (self-report)	60.44	< .001	0.35	1.54 (.95)	2.96* (1.66)	3.2* (1.74)
Goosebumps (self-report)	47.54	< .001	0.29	1.60 (.99)	2.96* (1.71)	3.07* (1.80)
Piloerection	.90	0.408	0.01	-0.991* (.09)	-0.965* (.22)	-0.965* (.18)

4.2. Sample 2

4.2.1. ***Did the videos elicit the expected self-reported emotions?*** There were no order effects for the gravity and buoyancy videos on awe (p = .259, d = .19) or surprise (p = .800, d = .04). Thus, the videos were analysed only in terms of expected vs. unexpected vs. Planet Earth.

The three videos differed on awe (F (1, 73) = 142.31, p < .001, η^2_p = .66), but not on surprise (F (1, 73) = 1.28, p = .262, η^2_p = .02). Importantly, the unexpected videos elicited more awe than the expected videos (t(73) = 5.08, p < .001, d = .77), and the Planet Earth video elicited greater awe compared to the unexpected (t(73) = 7.44, p < .001, d = 1.21) and expected videos (t(73) = 11.93, p < .001, d = 2.09). Means are reported in Table 2, below.

4.2.2. ***Does piloerection correlate with self-report measures?*** Piloerection was not strongly correlated with awe and surprise in each of the videos (rs < .06). See Table 2. As with Sample 1, the correlations between awe and piloerection did not differ meaningfully between the videos. A Fisher's r-to-z comparison between the expected and unexpected videos (the largest difference) yields z = .46, p = .645.

4.2.3. ***Frequency of piloerection.*** Finally, a repeated measures ANOVA indicates that piloerection scores do not differ across conditions, F (1, 66) = .06, p = .798, η^2_p < .01. As with sample 1, objective occurrence of piloerection was relatively rare overall (15% across all three videos). Counting those coded as both 0 (i.e. slight hair raised) and 1 (i.e. clearly visible piloerection), the counts were as follows. For the unexpected videos: n = 10. For the expected videos: n = 4. For the Planet Earth video: n = 11. Complete counts are presented in the supplementary materials (See Table S3).

Table 2. Mean piloerection scores, mean ratings of awe and surprise and the correlations among these measures in Sample 2. Piloerection ranged from -1 to 1; awe and surprise ranged from 0 to 100; **p < .01.

	Expected (n = 69)				Unexpected (n = 70)				Planet Earth (n = 68)			
Variable	***M***	***SD***	**1**	**2**	***M***	***SD***	**1**	**2**	***M***	***SD***	**1**	**2**
1. Awe	10.47	17.05			27.53	26.14			61.69	30.12		
2. Surprise	13.77	22.21	.53**		35.18	30.57	.45**		17.69	19.13	.36**	
3. Piloerection	-0.83	0.45	-0.03	-0.11	-0.94	0.24	0.05	0.06	-0.81	0.47	0.02	0.05

4.2.4. Quantifying evidence for a null effect. As with Sample 1, we observed many small and non-significant effects so we conducted supplementary Bayesian analyses. A repeated measures ANOVA comparing levels of piloerection across each of the three videos yields a BF_{10} = 1.66; this converts into a BF_{01} = .60 in favour of the null hypothesis. Thus, while our data is not consistent with the point null, there is not very strong evidence for the alternative hypothesis either. However, this averages across the three videos—two of which were hypothesized to elicit goosebumps.

Thus, to provide a more in-depth analysis, we computed paired samples t-tests to test the hypothesis that piloerection was greater in the unexpected vs. the expected condition but it was not (BF_{10} = 1.84). Second, there was much stronger evidence for the null effect (BF_{01} = 7.28) than for the hypothesis that the Planet Earth video caused greater piloerection than the expected videos. Finally, even though the Planet Earth and unexpected videos should elicit piloerection to a similar extent (and both greater than the expected video), evidence is slightly in favour of the Planet Earth video having greater piloerection scores BF_{10} = 5.43.

Thus, the next step is to examine the strength of evidence provided by the correlation analyses. We computed Bayes factors for the correlation between awe and piloerection in each of the three conditions, separately. In the expected video condition, a BF_{01} = 3.58 yields evidence in favour of a null correlation. In the unexpected video condition, a BF_{01} = 3.39 yields evidence in favour of the null. In the Planet Earth video conditions, a BF_{01} = 3.61 also yields evidence in favour of the null. In summary, all evidence for a null effect is greater than any observed estimates suggesting that piloerection is correlated with awe.

5. Discussion

Across two independently collected samples, and three types of stimuli selected to elicit various forms of awe, piloerection showed weak and inconsistent correlations with awe. Complementary Bayesian analyses also indicate much stronger evidence for a null effect across the two samples.

This aligns with recent physiological research also showing that awe is mostly unrelated to piloerection or the chills (Zickfeld et al., 2020). However, this contradicts one other study which claims to show that virtual reality causes both awe and goosebumps (Quesnel and Riecke, 2018). However, that study included only 16 participants and tested out only one kind of stimuli—virtual reality. It's worth noting that the largest correlation detected between awe and piloerection in the present data occurred for the virtual reality videos, though it was small ($r = .14$) and non-significant here. This could suggest that some aspect of virtual reality is effective at producing both awe and piloerection to some degree.

Relatedly, the main hypothesis of this paper was that stimuli eliciting awe would result in stronger awe-piloerection correlation. From the present data, this hypothesis received some support based on the correlations reported in Sample 1 (see Figure 1). However, awe and piloerection failed to co-occur or even correlate for any of the other awe-inducing stimuli used here. Thus, while the VR video elicited the greatest amount of awe and showed the strongest correlation with goosebumps, we urge caution in drawing very strong conclusions from these correlations on their own given the overall low frequency with which piloerection occurred.

The present studies were designed to maximise the experience of awe based on past theoretical descriptions and operationalisations. Indeed, the videos used in the present research reliably induced self-reported awe as indexed by two measures. The videos were also distinguishable in terms of related emotions (joy, surprise). However, the objective occurrence of piloerection was 1) rare, 2) not more likely for stimuli which elicited awe, and 3) not likely to correlate strongly with awe. Additionally, given that past research has found reasonable rates of piloerection occurring on forearms (Benedek and Kaernbach, 2011; Sumpf et al., 2015; Zickfeld et al., 2020), we would have expected much higher rates of piloerection if the stimuli actually caused goosebumps. That is, placement of our camera should not be an issue. Instead, we observed extremely low rates of piloerection, though we confirmed high rates of awe. In future studies, researchers may wish to continue to evaluate this relationship by gathering ratings of various emotions elicited by stimuli known to cause piloerection. Such videos, however, may not be effective at eliciting awe.

In the present study, subjects often reported experiencing chills and goosebumps. This is puzzling because piloerection did not accompany these experiences, in line with findings from past research (Benedek and Kaernbach, 2011). Participants' reports could be demand characteristics or they could be genuine reports of experiences which may not have a reliable (or consistent) physical manifestation. For example, participants may have experienced some physiological sensation (e.g., the chills) and assumed this was actually goosebumps. This may reflect a lack of interoceptive awareness, which can be influenced by many factors and varies widely among people (Ring et al., 2015). That is, some people may experience some subjective feeling but are unable to accurately track and evaluate the experience. Others may have been simply paying attention to the videos and not their own experience. Finally, it is also possible that piloerection may occur in one location on the body but not in others—future research will be needed to examine this possibility. However, given that past research has observed piloerection on the forearms, this possibility seems unlikely.

Finally, it's important to note that these results do suggest a relation between self-reported awe and self-reported chills and goosebumps in line with some survey research. For example, correlations in Sample 1 range from $r = .19$ to $r = .50$. However, there are several caveats to note before taking this result at face value. First, self-reported goosebumps do not reflect objective goosebumps, either here or in past research. Second, these results are likely due to demand characteristics because the pattern of correlations is not consistent with the hypothesized relation. For example, the awe *scale* correlates with chills and goosebumps for the control video—a video that should not elicit awe at all. In contrast, the awe *item* only correlated with self-reported chills and goosebumps for the emotional stimuli—stimuli which elicited lower overall levels of awe. Thus, it is possible that participants are experiencing a demand to report awe and goosebumps simultaneously. Such a demand could have been elicited by the instructions, by the description of the study, or by participants own beliefs that any physiological sensations they experienced actually indicate awe.

This pattern of results should be expected considering that awe and piloerection are associated with opposing markers of autonomic activity. Specifically, the arrector pili muscles are mainly under sympathetic control (Donadio et al., 2019) whereas awe is noted to be accompanied by markers of parasympathetic activity (Chirico et al., 2017; Shiota et al., 2011). Thus, despite the suggestions from self-report data, there is relatively little reason to expect that awe should be accompanied by piloerection. Future research should continue to investigate the physiological and emotional correlates of both awe and piloerection so as to better understand how and why these phenomena occur.

6. Concluding remarks

In conclusion, goosebumps do not appear to be a physiological measure of awe—at least awe in the sense that it is defined and operationalised in past experimental research. The present results cast doubt on descriptions of awe in the popular press and even on claims in some scientific articles. It's possible that experiences of awe yet unobserved in experimental research may be successful in eliciting piloerection, but experiences consistent with current operationalisations, used in previous research to elicit awe, do not reliably induce piloerection. Moving forward, more refined definitions of awe are needed. Researchers may wish to better define awe as an emotional and psychological state so that the causes of awe can be better understood.

Transparency statement

The study was pre-registered prior to data collection: https://osf.io/evtbj.

Data and materials are available online: https://osf.io/5q96f.

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